Low Noise Amplifier Receivers for Millimeter Wave Atmospheric Remote Sensing

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***Abstract* — We currently achieve 3.4 dB noise figure at 183GHz and 2.1 dB noise figure at 90 GHz with our MMIC low noise amplifiers (LNAs) in room temperature. These amplifiers and the receivers we have built using them made it possible to conduct highly accurate airborne measurement campaigns from the Global Hawk unmanned aerial vehicle, develop millimeter wave internally calibrated radiometers for altimeter radar path delay correction, and build prototypes of large arrays of millimeter receivers for a geostationary interferometric sounder. We use the developed millimeter wave receivers to measure temperature and humidity profiles in the atmosphere and in hurricanes as well as to characterize the path delay error in ocean topography altimetry.**

***Index Terms* — MMIC LNAs, Millimeter Wave Radiometers**

I. INTRODUCTION

The study of atmospheric dynamics and climatology depend on accurate and frequent measurements of temperature and humidity profiles of the atmosphere. These measurements furthermore enable highly accurate measurements of ocean topography by providing total column water vapor data for radar path delay correction. The atmospheric temperature profile is characterized at the oxygen molecule absorption frequencies (60 and 118 GHz) and the humidity profile at the water molecule absorption frequencies (23 and 183 GHz). Total column measurements can be achieved by comparing measured radiometric temperatures at atmospheric window channels, such as 90, 130 and 166 GHz. The standard receiver technology for these frequencies was diode mixers with MMIC LNAs being applied at the lower frequencies. The sensitivity of millimeter wave receivers improved significantly with the introduction of the low noise 35 nm gate length InP MMIC amplifiers.

II. LOW NOISE AMPLIFIER MMIC DEVELOPMENT

The development of low noise amplifier MMICs was based on a high performance 35 nm gate length InP HEMT technology from Northrop Grumman Aerospace Systems [1-3]. The 35 nm InP HEMT has demonstrated superior DC performance, including extremely high transconductance over 2000 mS/mm, sharp pinch off characteristics and reasonable output conductance. The 35 nm InP HEMT has a maximum available gain of over 10 dB beyond 180 GHz based on extrapolation of on-wafer measured S-parameters. This high maximum available gain enables matching of the HEMTs for optimum noise and still achieving sufficient gain for practical MMIC amplifiers to beyond 200 GHz.

The LNA MMICs [4],[5] were designed for various frequencies from 50 GHz to 180 GHz and beyond. They had two to four amplifier stages in common source configuration, and passive circuitry was designed typically with microstrip transmission lines on the 2 mil thick InP material. Fig. 1 shows photographs of the 180 GHz and 90 GHz MMIC LNAs.

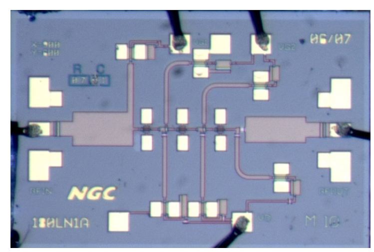

Fig. 1. Photograph of MMIC LNA designed and processed in 35 nm InP technology.

Our on-wafer measurement capability of S-parameters extends from DC to 500 GHz with dedicated frequency extension modules for each waveguide band. The MMIC amplifiers operate over a broad frequency range, so to measure the response of the MMIC amplifiers we used multiple frequency extenders. The 183 GHz LNA was measured with WR-10, WR-08 and WR-05 extension modules that were interfaced to 100-um, 100-um and 80-um pitch wafer probes, correspondingly. The 183 GHz amplifier demonstrated over 18 dB of gain from 100 GHz to 180 GHz as is shown in Fig. 2. Furthermore, there is gain beyond 220 GHz at higher than 15 dB level [11].

On-wafer measurements serve also the purpose of screening of the LNAs. The yield of packaged LNAs and receivers can become an issue if LNAs are not screened and only known good die used for assembly. On-wafer measurements of the LNA MMICs a quick and efficient screening method. Our typical wafer has hundreds of LNAs (of one type) and thousands of MMICs. Fig. 2 shows screening results of 180 GHz LNA MMICs.

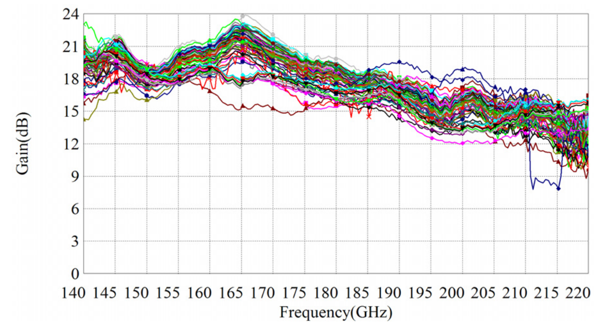

Fig. 2. The screening results of the broadband 180 GHz MMIC LNA on a wafer [11].

III. LOW NOISE AMPLIFIERS IN WAVEGUIDE HOUSINGS

The MMIC LNAs were packaged in waveguide housings for the characterization of the noise figure and for future use in instruments. For the measurement of the noise figure the LNA had an attached input horn and was followed by a double sideband mixer. We used an absorber as our hot and cold noise source in the Y-factor noise figure measurements. The hot temperature was the ambient (T= 295 K) and for cold load we dipped the absorber in liquid nitrogen (T=78 K) [6].

Packaging the 180 GHz amplifier in WR-05 waveguide packaging the results are seen in Fig. 3. The noise temperature was 300 K at 150 to 160 GHz and below 350 K over a broad frequency range. The 180 GHz MMIC LNA was also packaged in a WR-08 housing and measured in a similar setup as the WR-05 LNA. These results are also presented in Fig. 5 to demonstrate the broadband capability of the MMIC design. The MMIC LNA has less than 400 K noise temperature at 118 GHz temperature sounding line and at 183 GHz humidity sounding line. These results include the horn antenna, the waveguide inside the housing and waveguide to microstrip transitions. Fig.3 shows also gain and noise temperature results for 140 GHz LNA in WR-08 waveguide housing.

The 90 GHz MMIC LNA was packaged in WR-10 waveguide housing. The results of testing it are shown in Fig. 4. It had 200 K noise temperature at 95 GHz.

IV. AIRBORNE HIGH ALTITUDE MMIC SOUNDING RADIOMETER

HAMSR has temperature and humidity sounding radiometers at 55, 118 and 183 GHz. HAMSR was recently upgraded for flights on unmanned aerial vehicle (UAV) including fitting of the 180 GHz and 140 GHz LNAs in front end of the receivers [12]. HAMSR upgrade improved the noise equivalent delta temperature (NEDT) from more than 1 K to less than 0.1 K in large part due to the improved receiver noise temperature enabled by the 180 GHz LNAs. The HAMSR scene temperatures before and after the upgrade are shown in Fig. 5. [12].

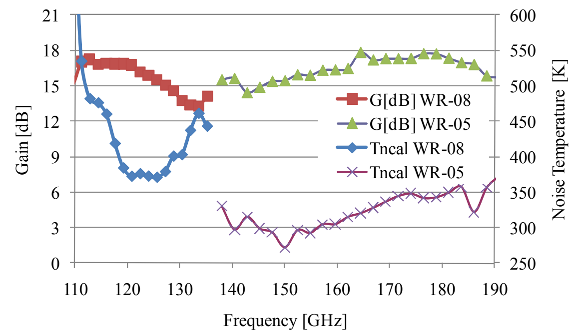

Fig. 3. Measured results for the 180 GHz MMIC LNA in WR-05 and WR-08 waveguide housings. The noise temperature (Tncal) of the MMIC LNA is 300 K at 150 to 160 GHz frequency range and less than 400 K from 118 GHz to 183 GHz.

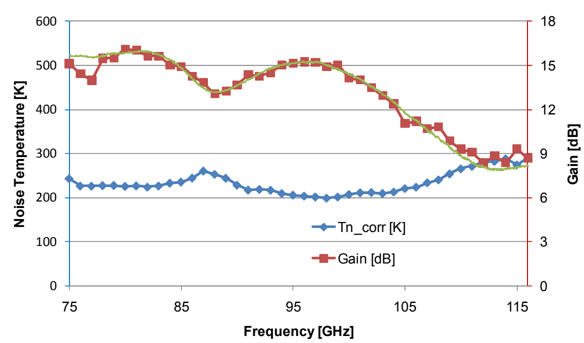

Fig. 4. Measured results for the waveguide MMIC LNA in WR-10 waveguide housing. The noise temperature (Tncal) of the MMIC LNA is 200 K at 95 GHz.

IV. RECEIVERS FOR GEOSTATIONARY SYNTHETIC APERTURE RADIOMETER

Continuous measurements of atmospheric temperature and humidity provide a key missing link in the climatic data record and weather forecasting. PATH (Precipitation and All-Weather Temperature and Humidity Mission) will enable uninterrupted observations of severe storms, tropical cyclones and atmospheric processes associated with the hydrologic cycle because of its geostationary orbit and the inherent capability of microwaves to provide measurements under all weather conditions. The Geostationary Synthetic Thinned Array Radiometer (GeoSTAR) is a microwave sounder concept based on aperture synthesis that was developed at the Jet Propulsion Laboratory for the PATH mission [7].

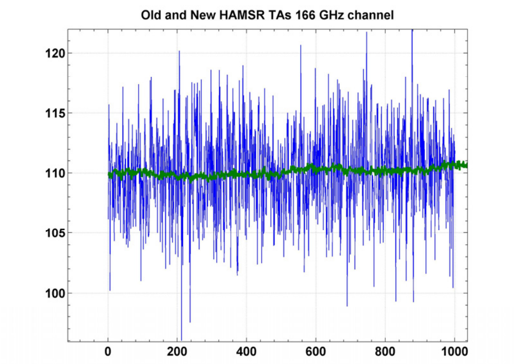

Fig. 5. HAMSR 180 GHz receiver upgraded LNA in front of the existing mixer NEDT improved by a factor of 10 to 0.1 K

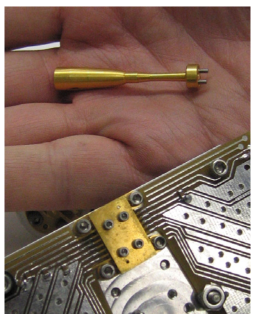

Fig. 6. The receiver module mounted on the testing platform and the parabolic potter horn antenna [13].

The critical noise performance (or sensitivity) of the system at 183 GHz was enabled by the highly sensitive 183 GHz MMIC LNA based IQ-receivers. Besides the noise temperature, power and mass are major technical challenges as the baseline flight system will include 312 receivers operating at 50 - 60 GHz and 768 receivers at 165 - 183 GHz that will be correlated to form the image of the hemisphere. at up to 25 km resolution. The 183 GHz InP MMIC LNAs allowed us to package the complete 183 GHz I-Q receiver in a miniature housing that will be enable integration of the GeoSTAR instrument [13]. Fig. 6 shows a picture of the receiver on a testing platform and a horn antenna for GeoSTAR.

V. RECEIVERS FOR CHARACTERIZATION OF HUMIDITY IN ATMOSPHERE

Conventional altimeters include nadir looking co-located 18-37 GHz microwave radiometer to measure wet tropospheric path delay. High-frequency window channels, 90, 130 and 166 GHz are optimum for improving performance in coastal region and channels on 183 GHz water vapor line are ideal for over-land retrievals. The 180 GHz MMIC LNAs enable us to develop internally calibrated direct detect radiometers at 166 GHz. Fig. 7 shows a picture of our current test bed radiometer system that has a noise temperature of 455 K, bandwidth of 10% and operates with 60 mW of DC power.

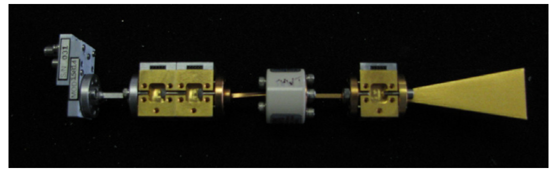

Fig. 7. 160 GHz total power radiometer for the SWOT testbed.

VI. CONCLUSION

The 180 GHz MMIC LNAs have demonstrated record low noise temperature of 300 K at room temperature. These LNAs are very broadband and enable improvement in sensitivity for multiple instruments currently in operation or development at JPL. Further applications of these LNAs are in astrophysics and millimeter imaging for security applications.

ACKNOWLEDGEMENT

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